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Guaranteeing the thermal and drinking water stations to operate under low Nile levels condition

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ABSTRACT

The paper proposes the procedures for thermal and drinking water stations to operate under different conditions of low water levels. Thermal power stations are constructed near water sources to use water for the operation and cooling of steam turbines, as well as cooling only in other types of turbines; gas and combined. Drinking water stations are distributed along the Nile River from Aswan to Delta in different capacities of operation. Hydrodynamic (1–D) model is applied to estimate the Nile levels corresponding to the minimum flow. The water level is estimated for different cross-sections along the reach with an interval of 10 km. The cross-sections are extracted using a geographic information system from contour maps. An equation is created to specify the amount of required water for thermal power stations. Four alternative solutions are introduced for ensuring the operation of each station and recommendations are suggested for different solutions if required.

Keywords: Thermal power station; Drinking water stations; Fourth reach of Nile River; G-star model; Regression model

1. Introduction

Providing safe water constantly at a high level must be the priority for the authorities in any country. Drinking water stations in Egypt consume approximately 18% of Egypt's annual Quota which is 55.5 billion cubic meters each year. With new conditions in the upper Nile countries and their new project of hydropower dams, Egypt's Quota is likely to decline. Due to that Nile River being the main source for drinking water stations and thermal power stations, most of these stations are distributed along its path. The power sector uses a substantial quantity of Nile water. With the new conditions for upper Nile countries, the operation of thermal and drinking water stations may be exposed to some problems leading to a reduction in their efficiency. The operation of those stations is affected by several factors including the elevation of their intakes corresponding to the water level in the Nile River. Furthermore, intake locations must account for factors that could affect performance and endanger the structure; such as sedimentation, scour cavitation and waves. The intakes are designed depending on the amount of water to be diverted, the amount of silt carried by the river and geomorphology of the river regarding the status of water level in the site. Other conditions can affect the operation; the bed level changes due to degradation or aggradation as well as Nile River morphology changes from one season to another. The distance between the bed levels- which represents the sedimentation- and the distance between the surface of the water for minimum level and the intake level- which represents the cavitation- play important roles in the operation. According to the sediment and cavitation phenomena; the safety distance is 2 and 0.5 m as a minimum distance in both respectively [1]. Different studies addressed the impact of water scarcity and the decline of levels on hydraulic structures such as drinking water stations and power stations. One of those studies talked about the water scarcity and its impact on the social and economic national projects in Egypt. The conclusion was the

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presence of some implications in implementing the upper Nile project. As a result, continuous reduction in the low flow years and sediment transport on river characteristics and equilibrium, in the long run, are evident. Also, Low current velocities and settling of sediment particles are evident. This might alter the water surface profile. Consequently, the navigation route and the operation of drinking and power stations might be affected [2]. Safeguarding the drinking water stations globally needs a wide variety of issues to be tackled, which encompass the construction of facilities to their maintenance. These issues include the refurbishment of aged facilities for which it is time to carry out the full-scale replacement, increasing resistance of facilities against earthquakes and their reform, preparedness against various risks such as terrorism or the new types of influenza, etc... In addition to preparedness against natural disasters such as earthquakes, floods, etc... [3]. The operation of a hydroelectric plant equipped with a water level controller as discussed in ref. [4] where analytical criteria for the stability of the controller under the downstream control method were derived. Optimum settings of the controller were obtained by numerical simulation of the system's time response. The hydro-economic model for water level fluctuations in lakes was discussed in ref. [5]. The hydro-economic model presents a fundamental method to start addressing the sustainable development of hydropower and drinking water production. It might be that the ecosystem's ecology can inform about specific requirements of 'environmental water levels'. Based on our hydro-economic model, it can then calculate how such 'environmental water levels' could be approximated. This will facilitate a compromise between the conservation of water levels relevant to the ecosystem and the maximization of energy production. In analogy to the provision of certain flows in the case of environmental flows, by the help of our model, research can be instigated that will allow for minimizing such losses of water for the operator while approximating environmental water levels. Such a methodology will ultimately advance our understanding of how efficient management can maximize both economic revenue and the ecological integrity of water resources.

Geographic information system (GIS) is used in many types of research to analyze and help to solve different problems such as this current research. Effects of drought conditions on electric power generation are studied through applying geo-database in the Western United States; it focuses on plant shutdowns or limitations due to low water intake levels caused by droughts. The study resulted in many important observations regarding the operation of the electric power system in the western United States and how system operation changes are caused by severe drought conditions, particularly in the near term (i.e., less than 10 years in the future) [6]. The monitoring of water levels of Kariba dam is followed through remote sensing and GIS, where the study extracted mapping of the Kariba Lake shoreline extent and discovered a general decrease in surface area of about

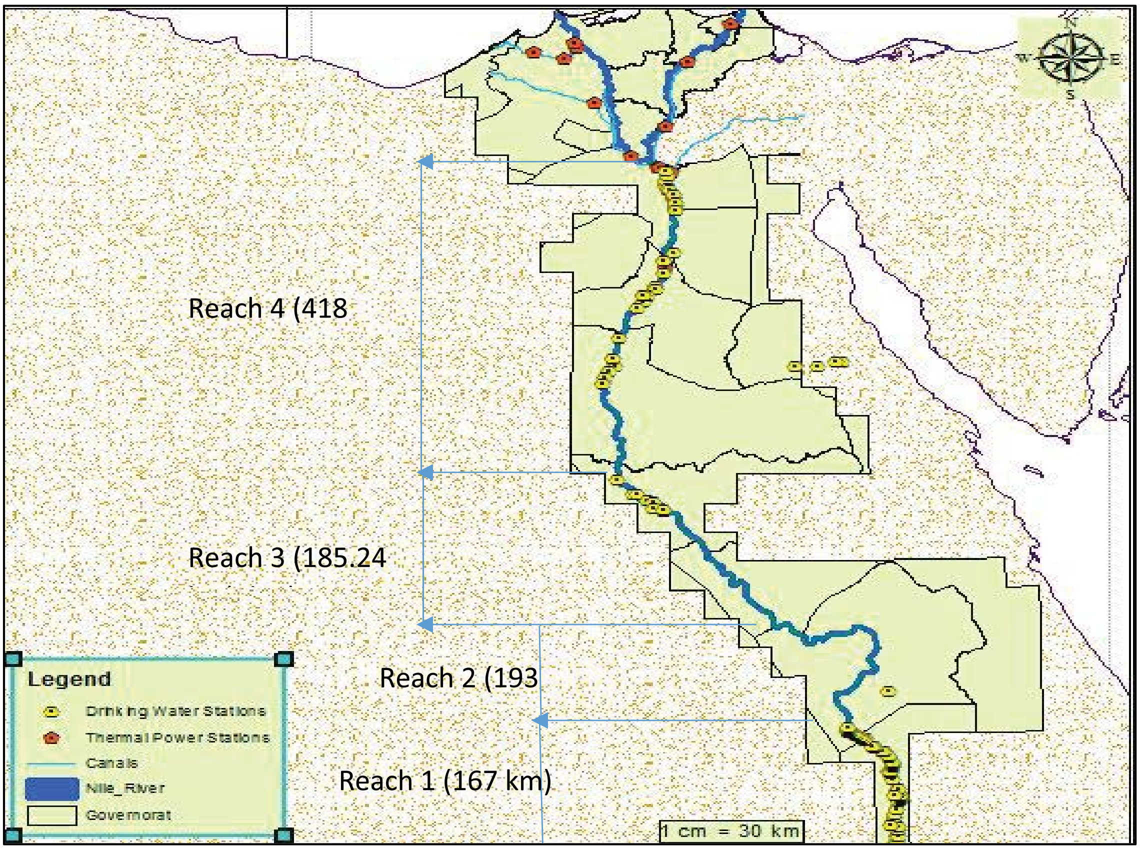


Fig. 1. Distribution of drinking water stations on the Nile and thermal power stations in the fourth reach.

4% from 1973 to 2015. The variation of the surface area of the Lake Kariba is mainly affected by the rainfall distribution patterns in the basin as highlighted by the positive correlation between the two variables, as well as other results that were obtained to help achieve the concerned objective [7].

In this research, the operation of both types of stations thermal and drinking water will be studied by applying a 1-D model to estimate the change in Nile levels corresponding to the minimum release. Many processes are followed to represent the operation status of the station's operation. This research is an attempt to enhance the drinking and thermal power stations under different Nile levels especially the low level in fourth and first reach. GIS module is established to assemble the data and facilitate the analysis. The hydraulic model (G-Star) is applied to estimate water levels. The regression equation is developed to specify the amount of required water for thermal power stations. A rating curve is produced to calculate the different levels corresponding to the flows, to compensate for the deficit of the water levels for safe operations.

2. Study location

Drinking water stations in Egypt are estimated to be around 830 stations distributed in all governorates. Fig. 1 shows the distribution of thermal power stations in fourth reach and drinking water stations for all reaches. Due to the lack of data available for drinking water stations, this study will cover the stations with available data. Fourth reach stations will be used for the study. Fig. 2 shows the critical elevation for drinking water stations in the Giza governorate [8]. Thermal power stations are the main source of electricity in Egypt. They count to around 36 stations, participating in power generation by 88.9% of the total generation in the country. Around 23 of them are distributed along the fourth reach and the two Branches. The total generation is estimated by 32,015 Mw for the year 2014 by an increased percentage of 3.9% than the year 2013. Fig. 2 represents the generation from different sources in Egypt. According to the generation, they are divided into four groups following four electricity Production companies; Cairo, East Delta, West Delta, and Upper Egypt. The used cooling water is varying from group to another. The range of water withdrawn in Upper Egypt is estimated by 2.7% annually from the Quota, East Delta group is estimated by 1.6% annually, and the West Delta group is estimated by 2.16% annually. According to the Cairo group, the cooling water is estimated by 3.96% annually, [9]. Fig. 3 shows the consumed water for different types of thermal power stations.

3. Problem definition

Specific water levels are needed for the safe operation of drinking and thermal stations. Levels lower than the specified ones for the safe operation could cause problems such as cavitation or sedimentation phenomena. It is expected that the water quota of Egypt will decrease shortly due to surrounding conditions in Africa. It should be noted that all

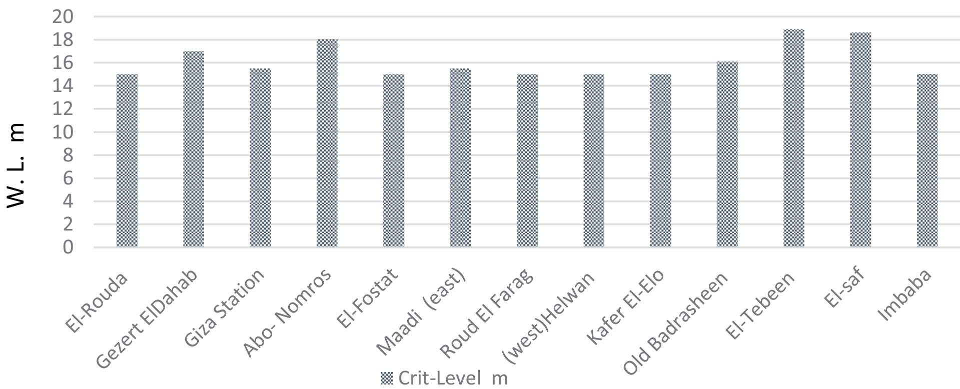


Fig. 2. Critical levels of intakes of drinking water stations in the Giza governorate [8].

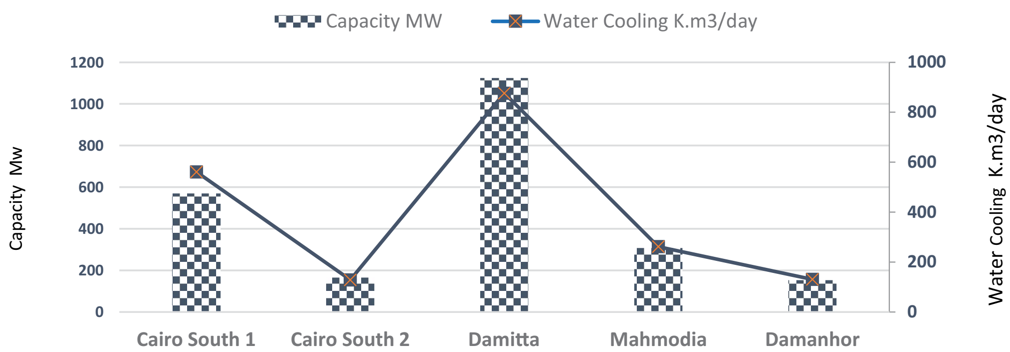


Fig. 3. Withdrawn water corresponding to the generation in combined and gas stations, fourth reach.

stations of thermal power generation and drinking water must be constructed where their intakes are located on specific levels. Changing the water levels at these stations is expected to cause the mentioned problems above and thus worsen the situation. This study will introduce a clear vision about the operation status of these stations and introduce changes in their location if necessary.

4. Methodology

Huge data is collected to develop a geo-database. Different inflows (two scenarios) are investigated to select the most effective for the operation of stations. Scenario 1 estimates the inflow by 37.7 M m^3 d^{-1}, which represents the minimum release and scenario 2 estimates the inflow by 30 M m^3 d^{-1}, which represents the worst release. Hydrodynamic model (GStar-W) is applied to estimate the water levels corresponding to the two releases. Rating curves are produced for different gauges to estimate the missing values of water levels. The regression model is used to estimate the relation between the generated capacities of thermal power stations and the consumed water. GIS package especially triangulation irregular network, GRID, various overlay methods, 3D analyst and spatial analyst are used to study how to cope with the impact of the two scenarios on the status operation of the stations.

4.1. Data collection and geo-database

The data is collected from different authorities; The Holding Company for Drinking Water and Wastewater-Water and Wastewater Facilities- Nile Research Institute-National Water Research Center- Ministry of Water Resources and Irrigation and Egyptian Electricity Holding Company-Ministry of Electricity and Energy. A series of database files are developed for the two types of stations. The files focus on specific data elements, such as stations' names, stations' capacity, source of consumed water, location (including latitude, longitude, and distance), normal and critical water levels for every station, generated capacity of thermal stations and the levels of intakes for both types of stations. Each file is organized differently but the common identifier in each file is a utility and station code. These codes were used to extract needed data elements from each file to combine them in a database that is created using Microsoft Excel. Several types of filtering are applied to remove incomplete or non-applicable data. After filtering, the final database contains different layers with a map for the Arab Republic of Egypt including the border of governorates, Nile River from Nasser Lake to the Mediterranean Sea, some canals in Delta region, thermal power stations and drinking water stations. The database covered 23 thermal power plants and 167 drinking water stations. There are around 96 stations from all drinking water stations studied and the operation status is specified. Fig. 4 shows the location of each station using latitude/longitude information and a GIS program. Overall, the database consists of the following;

- 23 thermal power plants in 8 governorates;
- 75 drinking water stations distributed along the first reach of the Nile River;
- 21 drinking water stations along the north of the fourth reach of Nile River and distributed in 5 governorates;
- The source for withdrawing water for all stations, (Nile River and Canals);

4.2. Work flow chart of processing

The study will be dealing with the minimum water level corresponding to the minimum release in the fourth reach which is 37.5 million m^3 d^{-1}. This is expected to occur with the conditions of the presented time and expectations that the water quota of Egypt will be decreasing. The Impact of the minimum of both release and water levels are studied as the worst scenario in the operation of the stations. Fig. 4 represents the flow chart of the process.

4.3. Model application

GStar-W model provides both steady and unsteady flow components to handle gradually varied flows and rapidly varied flows, both in a simple channel or a complex channel network. GStar-W model quasi-steady flow model represents an unsteady hydrograph by a series of steps of constant discharge Q with a finite duration Δt. The basic concepts for

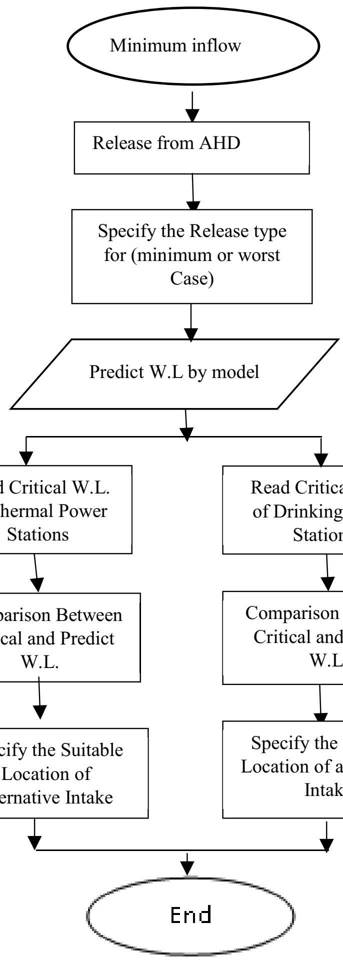


Fig. 4. Flow chart processing of the calculation.

water surface profile computational procedures are based on solving the energy equation using the standard-step method for subcritical flows where Nile River is categorized. The model will be applied to the fourth reach where the study stations are located.

4.3.1. Model input

The input files for the model contain forty cross-sections of data along the fourth reach by distance step 10 km as well as flow data in the two scenarios 1 and 2. Also, the roughness coefficient for each cross-section is included. The model boundary conditions are the discharge downstream of Asyut Barrage which is 37.7 M m^3 d^{-1} in the first scenario and 30 M m^3 d^{-1} in the second scenario with its corresponding water level downstream of Delta barrage of 15 m and 14.85 m for first and second scenarios respectively, as well as the time step which is one day.

4.3.2. Model calibration

A calibrated steady flow water-surface profile model should compute water surface elevations as observed elevations (from high water marks or gauge readings), not only for the set of conditions used in calibration but for others as well. This is accomplished with a trial-and-error procedure in which a water surface profile is computed with an initial set of parameters and compared to the observed data. The parameters are adjusted based on the comparison and the procedure is repeated until a suitable fit is obtained. The mathematical model was calibrated using the surveyed cross-sections and different water levels as well as the minimum downstream of Asyut Barrage and along the fourth reach, which was estimated at 15 m. The discharge values were identified from the actual measuring stations at different elevations along the reach. Fig. 5 shows the calibration for the fourth reach, at minimum release.

4.4. Specifying the water required for thermal power stations

The amount of required water used for cooling, operation or for both is varying according to the type of generation stations. Therefor steam and combined stations used the water for both operations and cool through the whole system. However, the other types of thermal stations such as gas consumed water to cooling only. Steam type consumed a huge amount of water. The relation between the consumed water and the value of electricity generated is developed using the regression model.

4.5. Ensuring the safe operation of the stations

The study introduces proposed solutions to ensure the safe operation for the drinking water stations; where the physical actual conditions around every station intake are not the same for all stations. Therefore the study suggested different solutions to cover all the problems at every station's intake, where all existing intakes are classified as free level intake type. The suggested solutions are as follows:

- *First*: construction of a barrier in the course before the intake location of the affected stations by a little distance to unmeet the water requirements. A barrier means any hydraulic structure to reserve the flow partially and raise the level such as weir. The engineering standards which must be considered when designing the weir are as follows [10]:
  - □ Hydrology considerations where they are specified with determining the type of the course (open channel).
  - □ Hydraulic considerations where they are related to the water level at the station which is studied with considering the Froud number for the stream, the width of the stream and the depth of the course.
  - □ The structural consideration where it is specified to raise the water level upstream the concerned station for a specific value that does not exceed 0.5 m.
- *Second*: removing the sediment front of the intake when its amount is small by an applicable method. This method is studied in the Ph.D. thesis [11]. The method steps are the following:
  - □ More than one sediment pump distributed around the mouth of the suction pipe of intake which must be submerged below the surface of the minimum water level by more than 2 m at the least below the level of the suction pipe.
  - □ The datum level of the sediment pump must be located below the level of entrance of suction pipe

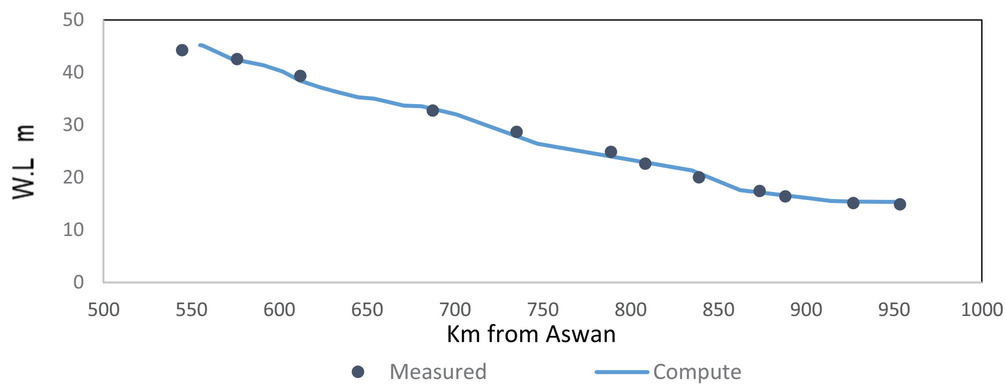


Fig. 5. Calibration for minimum release in the fourth reach.

by at least 1 meter to ensure continuous suction for the sediment before it reaches the suction pipe of the intake.

- □ The sediment pump can operate manually or automatically by electric sensors fixed in the suction pump to give the signals to the sediment pump to start working, where the sediment sensor level must be adjusted according to the characteristics of the station area.
- □ The room shape design of this system may be circular or rectangular and constructed from concrete with inside smooth lining and must be supplied with a movable gate system for maintenance of pumps and other components. Collected sediment can be collected in sediment tanks on the shore bank, which after drying, can be used for brick manufacturing and agriculture after being environmentally treated. A control and operation system must be located at the shore bank and there should be a trash rack system for cleaning anything around the system room.

With considering the relation between the rate of withdrawal of mud pumps and pumps drawing water into the station with:

$$Q_S \leq Q_P \quad (1)$$

where Q_S = total sediment pump rate (m h^{-1}), and Q_P = plant raw water pump rate (m h^{-1}).

- *Third*: new location of intakes considering its bed is available (alternative intakes) in terms of the rating curves and G-star model. Estimation of the new location of intakes corresponding to the predicted water levels after the decline at the studied stations occurs. Data of the year 2004 related to Korimate station at 87.8 km away from El-Rouda is used to produce the rating curve and its linear equation. Fig. 6 shows the rating curve.

$$\text{W.L.}_{\text{Korimate}} = 0.0216 \times Q + 19.442 \text{ m} \quad (2)$$

W.L. is the water level downstream Korimate station in (m), Q_{Korimate} = discharge downstream Edfo in (M m^3 d^{-1}), R^2 = Correlation factor was 0.9623.

- *Fourth*: dredging the course of the intake locations of the affected stations to ensure that the two phenomena -sedimentation and cavitation- do not occur, where this method is the common method used by the official authorities, [12]. In this method some steps are as follows:
  - □ Preparing the office data such as counter maps of the sites will be studied to determine the location and a suitable number of cross-sections.
  - □ Field trips to measure and gather the hydraulic data.
  - □ Analysis of data and extraction of the cross-sections to specify the status of the bed.
  - □ Calculation of the amount of dredging at every site.

5. Results and analysis

The decline of water level in the Nile and its impact on the operations of thermal power plants in the fourth reach as well as the drinking water stations in the same reach are studied. A spatial database is developed by using GIS to facilitate the analysis. Gstar model is applied to predict the water levels in two scenarios with the minimum case of release (Q = 37.7 M m^3 d^{-1}) and the worst case of release (Q = 30 M m^3 d^{-1}). Rating curves are drawn to help in specifying the locations of the alternative intakes of stations. Other processing is taking place to enhance the operation after specifying the statutes of every station with the two scenarios. The results are as follows:

5.1. Water level predicted in two scenarios

Prediction values of water level corresponding to the minimum release and expected worst release at fourth reach after the hydraulic model application of the two scenarios ranged between 15.04 m for the first scenario and 14.87 for the second scenario at El-Rouda Station. The output of the

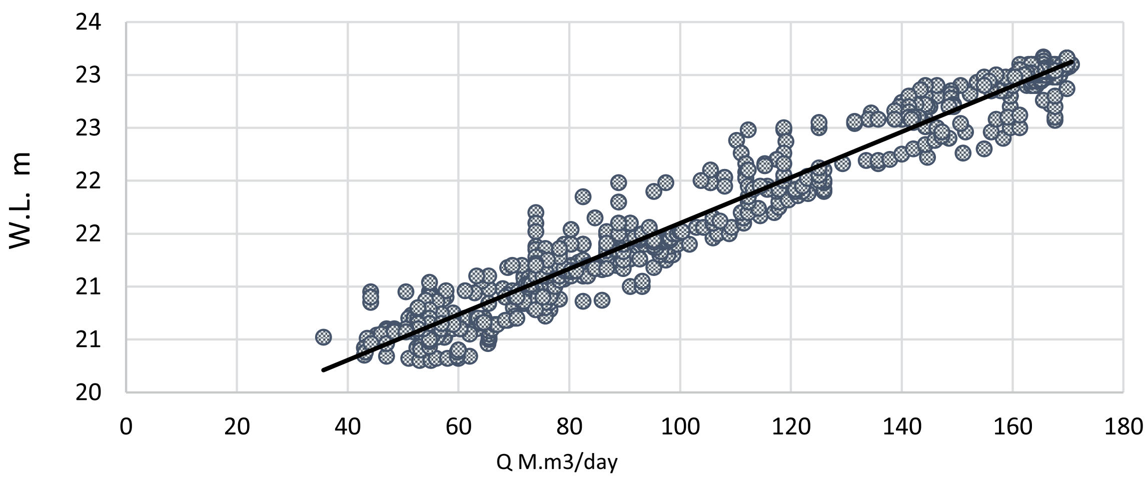


Fig. 6. Rating curve at Korimate, (at 87.8 km).

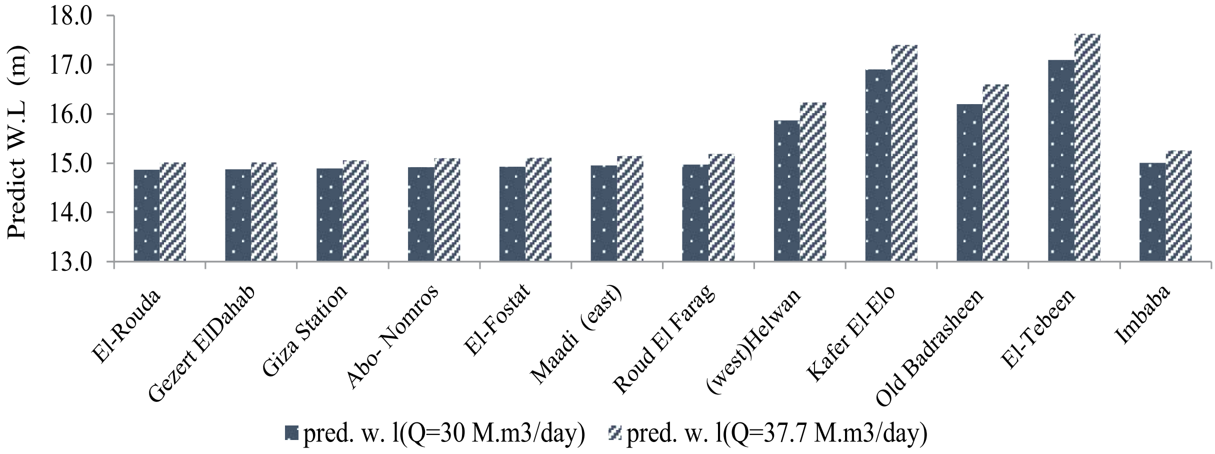


Fig. 7. The output of the hydraulic model at some of the drinking water stations.

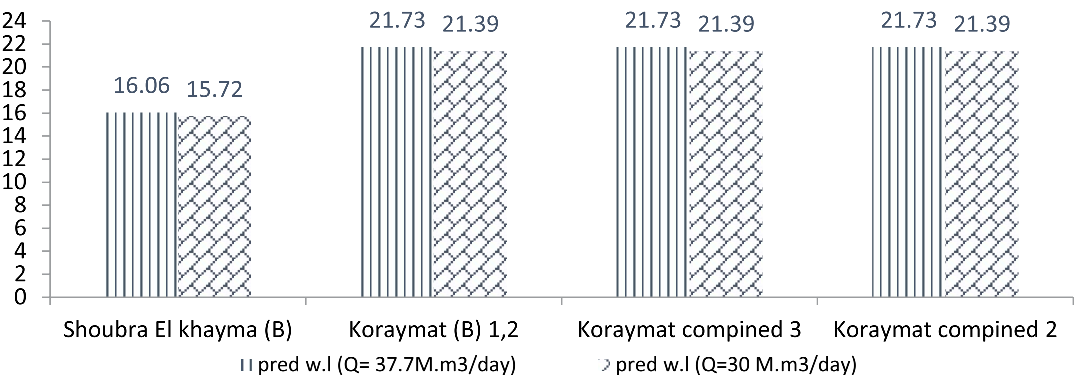


Fig. 8. The output of the hydraulic model at some of the thermal power stations.

model of the new water level values at around 12 drinking water stations and 5 thermal power stations is represented in Figs. 7 and 8.

5.2. Operation status of drinking water stations

Critical design levels of stations' intake ranged between 43.1 and 40.3 m at the start of reach – Asyut governorate - but the values at the end of the reach - the region including Giza and Cairo governorates - ranged between 16.11 and 15 m. Predicted values of water levels at each station corresponding to the two scenarios are compared with the critical design levels of the stations' intakes. The operation status of stations is divided into three categories. Category 1: where predicted water levels are closed with the critical design levels of some stations' intakes such as El-Qousia, Imbaba, Old Badrasheen, Kafr El-Elo, and Helwan West stations. These stations are not affected by the two scenarios and their operation is good. Category 2: where stations were not affected by the minimum release (scenario 1) but are affected by the

Table 1
Sample of drinking water stations operation status in the two scenarios

Station name	km	Critical-level (m)	w. l (Scenario 1)	w. l (Scenario2)
El-Rouda	0.3	15	14.87	15.01
Giza station	2.6	15.5	14.90	15.06
El-Fostat	5	15	14.92	15.11
Maadi (East)	7.1	15.5	14.95	15.15
Rod El Farag	8.6	15	14.97	15.19
Helwan (West)	18.45	15	15.87	16.23
Kafr El-Elo	24.9	15	16.90	17.40
Old Badrasheen	20.5	16.11	16.20	16.60
Imbaba	12.5	15.02	15.01	15.25

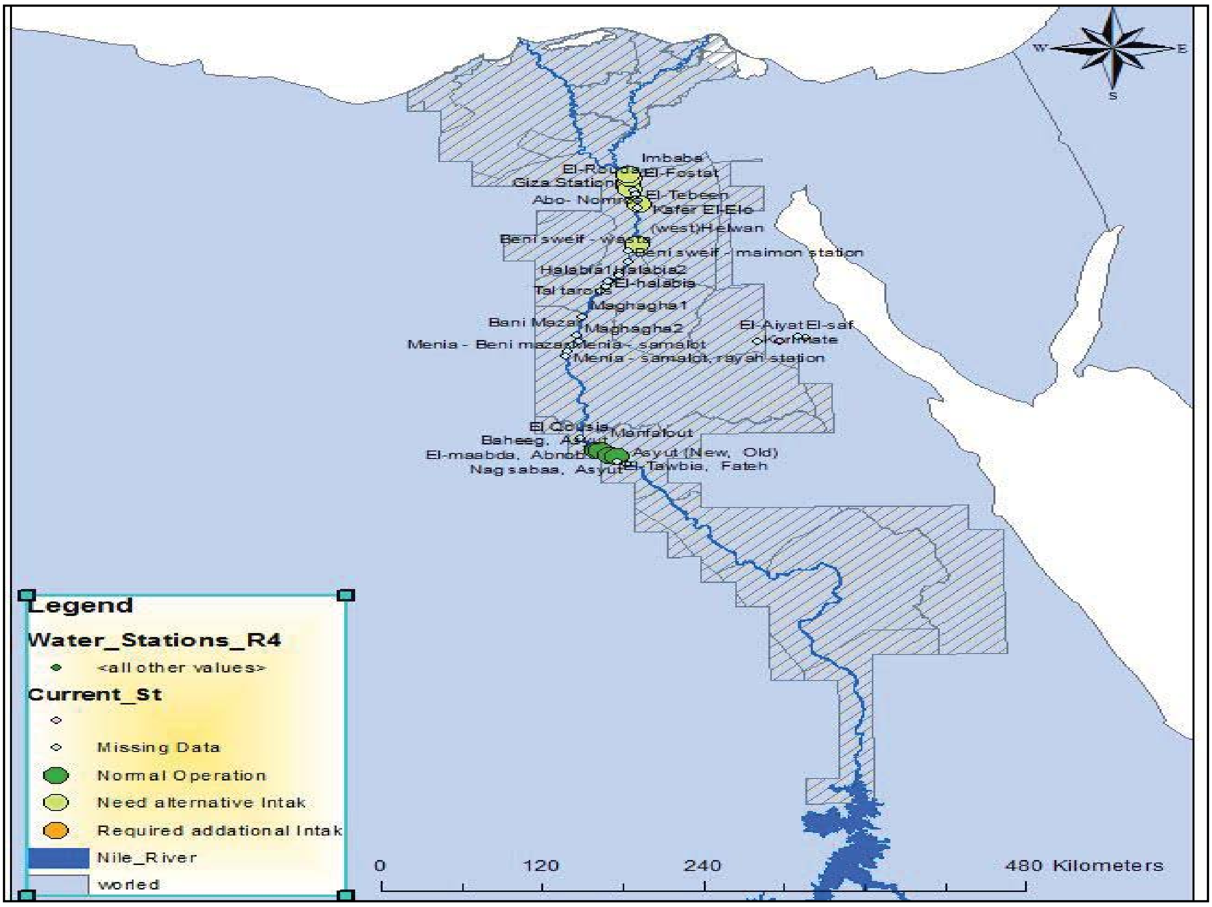


Fig. 9. Classification of drinking water stations in the fourth reach according to operational status.

worst release (scenario 2) such as El-Rouda, El Fostat, and Rod El Farag stations. Category 3: where stations are affected by the two scenarios and are expected to be stopped such as Giza and El Maadi stations. Fig. 9 shows the classification of drinking water Stations in the fourth reach. Table 1, tabulated the operation of drinking water stations in two scenarios.

5.2.1. Ensuring the operation of the affected stations

Four alternative solutions are introduced in this approach. According to the first solution, collected required data to study these points shows that the solution is not applicable as it came into conflict with the Egyptian policy to deal with the Nile because any hydraulic structures such as berries across the Nile waterway is prohibited in respect to the navigation path through the Nile as well as other factors. Yet, the solution is accepted for the small canals which are not included in the navigation path with following the principle of engineering as it is mentioned. The second solution is discussed and implanted through a physical model but is not used as an actual solution. The third solution can be implemented through some processing as follows;

- Preparing the hydrographic maps contour maps (NRI-2007) at the intake of every station to be digital elevation model by using a GIS package; spatial analyst tool.
- Create cross sections to specify the status of the bed at the intake locations.
- Apply the two safety factors of operation: elevation of intake must be up to the bottom by 2 m and down the surface of the water by 0.5 m as minimum values to specify the suitable locations of alternative intakes.

Fig. 10 represents cross-sections at intakes of El Maadi and Rouda stations as a sample of the affected stations. The location of the intakes of both stations is on the east side of the Nile River, where the status of the bed is good. There is no sediment; therefore 1 m drop in the elevation of the intakes in both stations can be achieved. Table 4 shows the suitable elevation of the alternative intakes for the affected five stations.

The fourth solution is already used by the official authorities and applied with the normal water level on some drinking stations such as Rod El Farag and El Fostat, where Rod El Farag station has three intakes and the maximum and minimum water levels at the study time are 17.27 and 16.05 m respectively. The study depended on six cross-sections for a distance of 325 m. The first and second cross-sections are located at the south and north of the south intake. The third and fourth cross-sections are south and north of the second intake. The fifth and sixth are south and north of the third intake. Fig. 11 represents a sample of a cross-section (fifth cross-section), where the amount of dredging is calculated as 1,418.2 m^3. According to El Fostat stations, it has

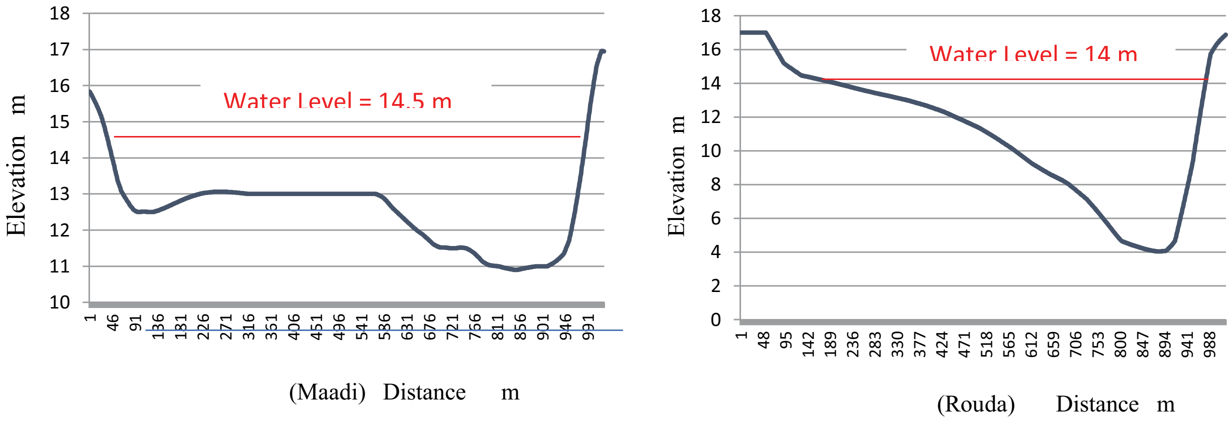


Fig. 10. Cross-sections at El Maadi and Rouda intakes.

Table 2
Elevation of alternative intakes for the affected stations, fourth reach

Station name	Distance from El-Rouda, (km)	Alternative intake elevation to enhance the operation, (m)
El-Rouda	0.3	14
Giza station	2.6	14.5
El-Fostat	5	14.5
Maadi (East)	7.1	14.5
Rod El Farag	8.6	14.4

two intakes and the maximum and minimum water levels at the study time are 17.86 and 16.37 m respectively. The study depended on two cross-sections at the two intakes for a distance of 125 m. Fig. 12 represents the cross-section at the first intake and the dredging is calculated as 8,093 m^3.

5.3. Operation status of thermal power stations

The operation status with two scenarios for thermal power stations is specified; all studied stations operate in safe mode with minimum release and worst release, where the prediction of water levels in two cases more than the

Table 3
Predicted values of W.L. for thermal power stations in two scenarios

Stations	km	Min. W.l	Critical-Level (m)	w. l (Scenario 1)	w. l (Scenario 2)
Shoubra El Khayma (B)	17.5	–		16.06	15.72
Koraymat (B) 1,2	91.3	20.5	20.5	21.73	21.39
Koraymat combined 3	91.3	20.05	19.1	21.73	21.39
Koraymat combined 2	91.3	20.5	19.85	21.73	21.39

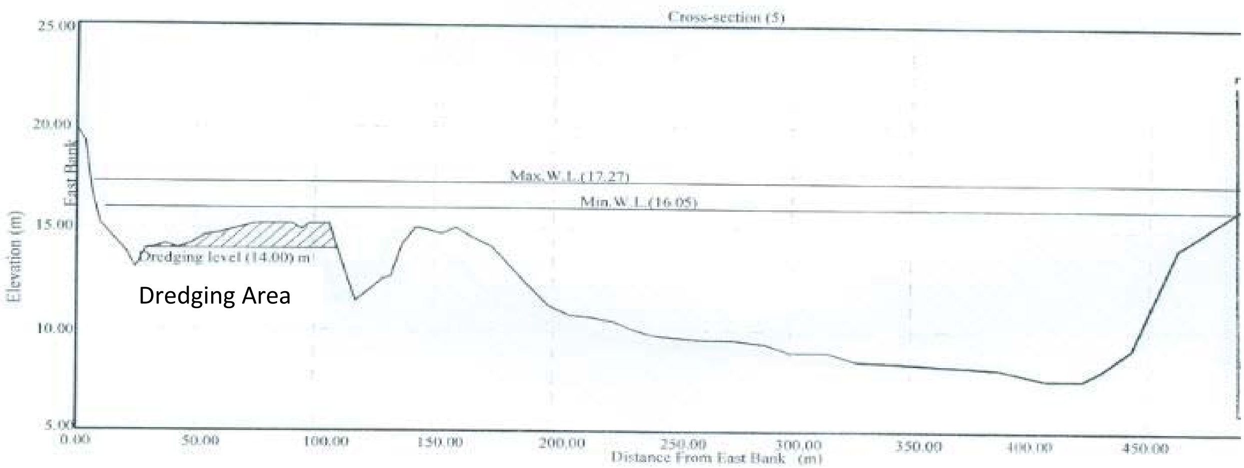


Fig. 11. Cross-section 5 at third intake Rod El Farag, [12].

critical values of stations intakes. Fig. 13 and Table 3 represent this result and the operation status of stations.

5.4. Required water vs. generation capacity of thermal power stations

The normality of steam station data is achieved. Figs. 14a and b show that. Eq. (3) represents the amount of required water in terms of the generated value for steam stations. The analysis of variance for the equation is tabulated in Table 4, where P values indicate that the relationship between the generation capacity of station and water required is statistically significant. Also, the correlation factor (R^2) value shows that capacity and water cooling elucidate 96% which is indicating that the model fits the data extremely well.

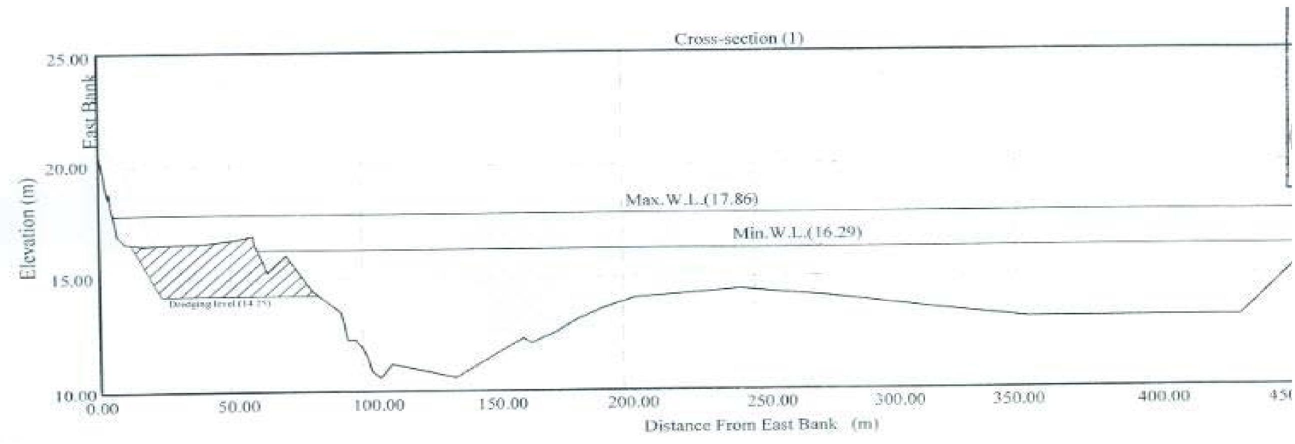


Fig. 12. Cross-section 1 at the first intake of El Fostat, [12].

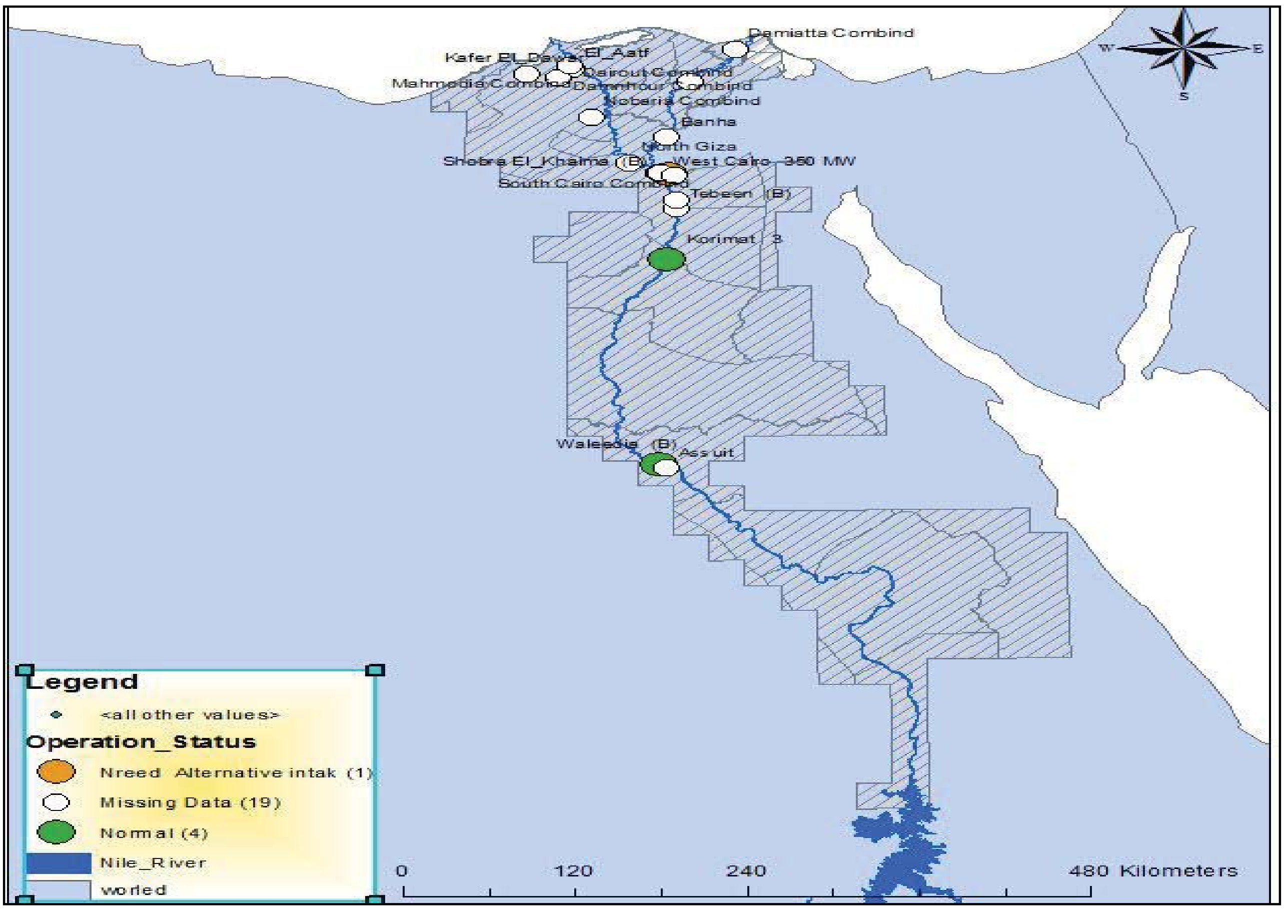
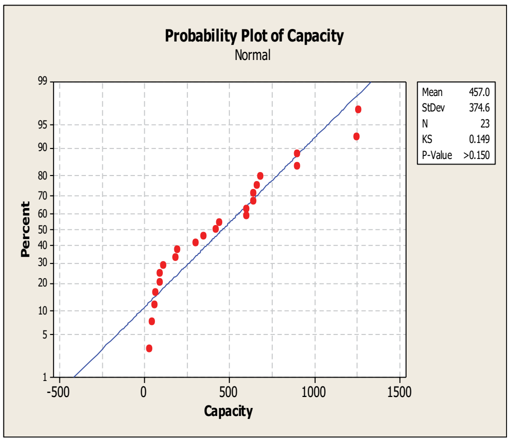
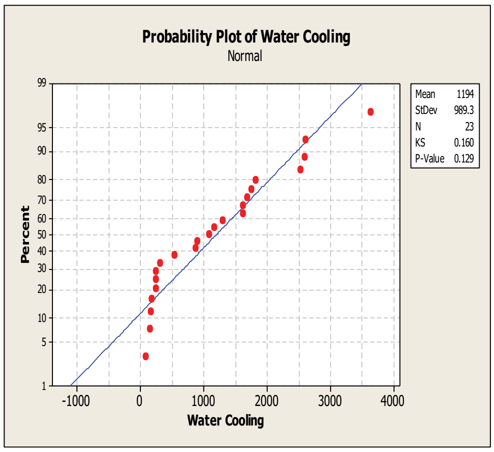


Fig. 13. Classification of thermal power stations in the fourth reach according to operational status.



(a)



(b)

Fig. 14. Normal probability data of generation capacity and water consumption in steam stations.

Table 4
Variance analysis of Eq. (2)

Source	DF	SS	MS	F	P
Regression	1	20,669,122	20,669,122	503.52	0.000
Residual error	21	862,037	41,049		
Total	22	21,531,159			

Regression equation of steam stations;

$$W_c = 11.8 + 2.59G_s \quad (3)$$

where R-Sq = 96.0%; W_c = water consumed by steam stations (K m^3 d^{-1}); G_s = generated electricity power by steam station (capacity of station) MW

6. Conclusion and recommendations

The operation status of thermal and drinking water stations along the fourth reach is studied. The study focused on the minimum release, where Q is 37.7 M m^3 d^{-1} (scenario1) and worst release where Q is 30 M m^3 d^{-1} (scenario 2). Hydrodynamic model 1-D (Gstar–w) was applied to predict the water levels with the two scenarios. Regression Equation is created to develop the relationship between the consumed water and the values of generated power from thermal power stations. The results are concluded that; five drinking water stations (Rouda, Giza, Fostat, Maadi, and Rod El Farag stations) are affected, dropping their intakes from half to one meter to achieve the safety operation. According to thermal power stations; all stations operate safely with the two scenarios.

To avoid the effect of the minimum and worst releases on the stations and to ensure the operation of the affected different water stations, four alternative solutions were introduced to ensure the operation of drinking water stations that have been affected. The first, second and third alternatives considered proposed solutions but not implemented. According to the fourth alternative, it is implemented but with a normal case for two drinking stations: Rod el Farag and El Fostat. The amount of dredging for both Rod el Farag and El Fostat stations is 1418.2 and 8093 m^3 respectively. So, it is recommended to do another study to select the best and the most economical solution that can be used. It's also recommended to give answers to these questions: what is the best solution for the problem in the normal case and what is the best solution for the worst case? The Regression Equation is developed to help the decision-makers to handle the generation according to the specified required consumption of water for steam stations. This study must be applied to all hydraulic structures on the Nile River to assess their operation status.

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